

DTIC FILE COPY

SECURITY CLASSIFICATION OF THIS PAGE

AD-A218 001 DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

| | | | | | |
|---|-------|--|--|---|--------------------|
| 1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED | | | 1b. RESTRICTIVE MARKINGS NONE | | |
| 2a. SECURITY CLASSIFICATION AUTHORITY | | | 3. DISTRIBUTION / AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED | | |
| 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE | | | | | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | | | 5. MONITORING ORGANIZATION REPORT NUMBER(S) AFIT/CI/CIA-89-121 | | |
| 6a. NAME OF PERFORMING ORGANIZATION AFIT STUDENT AT RICE UNIVERSITY | | 6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION AFIT/CIA | | |
| 6c. ADDRESS (City, State, and ZIP Code) | | | 7b. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6583 | | |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION | | 8b. OFFICE SYMBOL (If applicable) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER | | |
| 8c. ADDRESS (City, State, and ZIP Code) | | | 10. SOURCE OF FUNDING NUMBERS | | |
| | | | PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. |
| | | | WORK UNIT ACCESSION NO. | | |
| 11. TITLE (Include Security Classification) Cognitive Organization in Chess: Beyond Chunking | | | | | |
| 12. PERSONAL AUTHOR(S) Robert C. Berger | | | | | |
| 13a. TYPE OF REPORT THESIS | | 13b. TIME COVERED FROM _____ TO _____ | | 14. DATE OF REPORT (Year, Month, Day) May 1989 | |
| 15. PAGE COUNT 50 | | | | | |
| 16. SUPPLEMENTARY NOTATION APPROVED FOR PUBLIC RELEASE IAW AFR 190-1 ERNEST A. HAYGOOD, 1st Lt, USAF Executive Officer, Civilian Institution Programs | | | | | |
| 17. COSATI CODES | | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) | | |
| FIELD | GROUP | SUB-GROUP | | | |
| | | | | | |
| | | | | | |
| 19. ABSTRACT (Continue on reverse if necessary and identify by block number) | | | | | |
| <div style="text-align: center;"> DTIC ELECTE S FEB 13 1990 D CO D </div> <div style="text-align: center; font-size: 2em; margin-top: 20px;">90 02 12 025</div> | | | | | |
| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS | | | 21. ABSTRACT SECURITY CLASSIFICATION | | |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL | | | 22b. TELEPHONE (Include Area Code) | | 22c. OFFICE SYMBOL |

Cognitive Organization in Chess: Beyond Chunking

Robert C. Berger

Abstract

Three experiments investigated cognitive organization in chess. The conventional view of perception in chess is the recognition-association model which emphasizes perceptual chunking as a basis for expertise. These experiments explored an alternative hypothesis that a higher level cognitive organizing process allows experts to integrate and perceive a position as a whole, rather than merely as a collection of perceptual chunks. In the first two experiments, subjects were presented with chess positions and high level descriptions of those positions either before or after position presentation. In both experiments, recall in the description-before condition was superior, supporting the importance of a higher level cognitive organization. The third experiment contrasted recall of positions presented by chunk with positions presented by pawn structure. Results showed recall was similar in the two conditions, again lending support to the idea that more than chunking is involved in the expert's perception and recall of a chess position. (5/11)

-11

8-121

RICE UNIVERSITY

COGNITIVE ORGANIZATION IN CHESS: BEYOND CHUNKING

by

ROBERT C. BERGER

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
MASTER OF ARTS



APPROVED, THESIS COMMITTEE:

David M. Lane
David M. Lane, Associate Professor
of Psychology, Co-director

Nancy M. Cooke
Nancy M. Cooke, Assistant Professor
of Psychology, Co-director

William E. Howell
William E. Howell,
Professor of Psychology

| | |
|--------------------|--|
| Accession For | |
| NTIS CRA&I | <input checked="checked" type="checkbox"/> |
| DTIC TAB | <input type="checkbox"/> |
| Unannounced | <input type="checkbox"/> |
| Justification | |
| By | |
| Distribution / | |
| Availability Codes | |
| Dist | Avail and/or Special |
| A-1 | |

Houston, Texas

May 1989

RICE UNIVERSITY

COGNITIVE ORGANIZATION IN CHESS: BEYOND CHUNKING

by

ROBERT C. BERGER

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
MASTER OF ARTS

APPROVED, THESIS COMMITTEE:

David M. Lane, Associate Professor
of Psychology, Co-director

Nancy M. Cooke, Assistant Professor
of Psychology, Co-director

William C. Howell,
Professor of Psychology

Houston, Texas

May 1989

90 62 11 22

Acknowledgements

I would like to thank my thesis co-directors, David Lane and Nancy Cooke for their patience, inspiration, and ideas. Without them, this project would not have been possible. The advice and support of Bill Howell was invaluable in completing this work. Finally, I could not have done this study without the unswerving encouragement and understanding of my wife, Diane, who kept the home front running smoothly during my physical and psychological absence.

Table of Contents

| | <u>Page</u> |
|--|-------------|
| Abstract | i |
| Acknowledgements | ii |
| Table of Contents | iii |
| List of Tables | v |
| List of Figures | vi |
| Introduction | 1 |
| Study of Domain-Specific Expertise | 1 |
| Chess as a Domain for the Study of Expertise and Problem Solving | 2 |
| The Recognition-Association Model of Skill in Chess | 5 |
| Problems with the Recognition-Association Model | 6 |
| An Alternative to the Recognition-Association Model | 8 |
| Experiment 1 | 11 |
| Results | 14 |
| Discussion | 14 |
| Experiment 2 | 15 |
| Results | 16 |
| Discussion | 19 |
| Experiment 3 | 21 |
| Results | 24 |
| Discussion | 28 |
| General Discussion | 29 |

| | |
|--|----|
| References | 32 |
| Appendix A-The Elo Rating System | 35 |
| Appendix B-Positions Used in Experiments 1 and 2 | 37 |
| Appendix C-Positions Used in Experiment 3 | 39 |
| Appendix D-Questionnaire Used in Experiment 3 | 40 |
| Appendix E-Results of Experiment 1 | 41 |
| Appendix F-Results of Experiment 2 | 43 |
| Appendix G-Results of Experiment 3 | 47 |

List of Tables

| | <u>Page</u> |
|--|-------------|
| Table 1- Percentage of Correctly Placed Pieces in Experiment 1 | 14 |
| Table 2- Percentage of Correctly Placed Pieces in Experiment 2 | 17 |
| Table 3- Percentage of Correctly Placed Pieces in Experiment 3 | 24 |

List of Figures

| | <u>Page</u> |
|--|-------------|
| Figure 1- An Example of a Position Used in Experiments 1 and 2 | 12 |
| Figure 2- Experiment 2 Serial Position Effect | 17 |
| Figure 3- Exp 2: Correlation of Rating With Overall Performance | 18 |
| Figure 4- An Example of a Position Used in Experiment 3 | 22 |
| Figure 5- Comparison of Pawns vs Chunks | 25 |
| Figure 6- Exp 3: Correlation of Rating With Overall Performance | 25 |
| Figure 7- Exp 3: Serial Position Effect Across Conditions by Expertise | 26 |
| Figure 8- Exp 3: Serial Position Effect Chunk vs Pawn by Expertise | 27 |

Introduction

One approach to studying human problem solving and expertise is to study the solution of general or domain-free problems; problems understandable by a wide range of subjects without any specific domain reference. Gestalt psychologists pioneered many of the early experiments using domain-free problems. Studies of the "water jar problem" in which subjects had to produce a specific amount of water by combining water from fixed capacity jars (Luchins, 1942) led to the concept of mental set--the idea that people tend to use solutions that have worked in the past, even if easier solutions are available. Other studies (Duncker, 1945) showed how people tend to think of items or objects having only one function, a characteristic of problem solving called functional fixedness.

After the dawn of the computer age, general problems like river crossing problems, in which the problem solver must decide how to transport people or animals across a river in a limited-capacity boat with specific constraints, and the Tower of Hanoi problems were used to investigate the use of heuristics, algorithms, and means-end analysis (Best, 1989). Much of this research was done in the spirit of an analogy between the human and the computer. Attempts to generalize these findings to real world problems were somewhat disappointing and led researchers to another major approach to the study of problem solving--the study of domain-specific expertise.

Study of Domain-Specific Expertise

Expertise has been studied over a wide range of domains including computer programming (McKeithen, Reitman, Rueter, & Hirtle, 1981; Shneiderman, 1976), physics (Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980), diagnostic radiology (Worsley, Johnston, & Simons, 1988), the Oriental game of Go (Reitman, 1976), bridge (Engle & Bukstel, 1978), music (Sloboda, 1976), and chess (DeGroot, 1965; Chase and Simon, 1973a; Charness, 1976; Frey & Adelman, 1976).

Research has focused on how experts perceive and organize domain-relevant material. The goal of this previous research and the research reported here is to extend current findings of expert perception and cognitive organization. Potential applications of this work include the training of experts in various domains and expert system development, particularly in the area of knowledge engineering.

Chess as a Domain for the Study of Expertise and Problem Solving

It is no accident that cognitive psychologists have repeatedly used the game of chess to study problem solving and knowledge organization. Chess has proven to be a rich domain because of its complexity, and yet has been amenable to analysis because of its well-defined rules and clear outcomes. A major advantage of chess as a domain for studying expertise is its precise rating system. Virtually all serious chess players are rated by the same system. (See Appendix A for a detailed discussion of the rating system.) Few domains have such explicit definitions of levels of expertise and precise rankings of its practitioners. Because of this, experimenters in other domains have had to use subjective definitions of expertise such as domain experience versus no domain experience (Sloboda, 1976), job title (Egan & Schwartz, 1979), number of college courses taken (McKeithen, Reitman, Rueter, & Hirtle, 1981), or years of domain experience (Myles-Worsley, Johnston, & Simons, 1988). The precision of rating makes chess an extremely useful domain to study perception and problem solving across varying levels of expertise.

Chess certainly qualifies as a complex and knowledge-rich domain. The approximate number of possible different moves in a game has been estimated to be a staggering 10^{120} (Shannon, 1950)! To put this number in perspective, Holding (1985) states scientists have estimated that only 10^{75} seconds have elapsed since the origin of the universe. Further evidence of the complexity of chess is the failure to develop a computer

chess program that can beat the top human chess players, even though Shannon (1950) laid out the basic principles for programming a computer to play in 1950, and in 1958 Herbert Simon predicted that a computer would be world champion by 1968 (Simon & Newell, 1958). Although vast improvements in computer play have been achieved, this goal has not been reached because of the vast complexity of chess.

Psychologists have long been interested in determining what makes a good human chess player. In the 1890's, Alfred Binet studied blindfold chess players (Binet, 1893/1966). One of Binet's conclusions was that players remember moves and positions by using a central guiding idea, like remembering a well-reasoned argument. Among his other conclusions was the claim that understanding the ideas, reasoning, and strategies of a game are more important to remembering positions than recalling individual moves and individual piece placement. Alfred Cleveland, the first American psychologist to study chess (Cleveland, 1907), wrote a paper based on his personal introspections about learning how to play, and on anecdotal evidence from numerous highly rated players. Cleveland maintained that chess specific memory was based upon a skill-correlated ability to "comprehend the board as a whole." Good players, according to Cleveland, can "feel" a position and judge it at a glance. That expert players can recall positions after glancing at them was later empirically demonstrated (DeGroot, 1965). Cleveland felt that experience leads to a "dropping out" of intermediate processes of inference. Unfortunately, much of Binet's and Cleveland's work was based on introspective methods in keeping with the psychology of the era. However, many of the ideas of Binet and Cleveland, in modified forms, have been put to empirical test by subsequent researchers.

Despite the long history of chess studies, there is no conclusive evidence that chess skill depends on any general cognitive abilities like intelligence, mathematical aptitude, or spatial ability (Holding, 1985). Chess researchers have also investigated

more chess-specific skill like the popular notions that chess masters can search deeper (this was one of Cleveland's major contentions) or consider more moves than novices. The Dutch psychologist DeGroot explored this hypothesis and was unable to find differences between masters and weaker players in terms of the number of moves each considered and how deep they searched (DeGroot, 1965). DeGroot analyzed the following eight variables during a move selection experiment:

- 1- time used to decide move
- 2- number of fresh starts
- 3- number of first moves considered
- 4- maximal depth calculated
- 5- total number of move possibilities considered
- 6- number of moves considered/minute
- 7- number of different first moves considered/minute
- 8- value of the selected move

DeGroot's analysis of the protocols of five grandmasters and five masters found no difference between skill levels for the first seven variables considered. The only significant difference was in the value of the move finally selected. The higher the player's rating, the better the move he selected. DeGroot's conclusions regarding no difference in depth or width of search have since been challenged by Charness (1981) who found differences based on skill level by using a different experimental design (Charness used multiple positions while DeGroot used only one) and a wider range of skill level. Holding and Reynolds (1982) have also challenged DeGroot's conclusion and contend that higher-rated players can search deeper. Despite these challenges to DeGroot's conclusions that no differences exist in the search statistics of expert and lower rated players, most of the recent efforts investigating chess skill have centered around perception.

The Recognition-Association Model of Skill in Chess

DeGroot (DeGroot, 1965; DeGroot, 1966) also performed the pioneering work in the area of perception in chess. He exposed both masters and weaker level players to briefly presented (2 to 15 seconds) positions, and tested them on their ability to accurately reconstruct the positions. He found significant differences between masters and weaker players in this task. This finding, by itself, is not particularly surprising, but the work led to an experimental paradigm for studying perception in chess. DeGroot's findings have been replicated a number of times by different researchers using modified versions of the original task (Chase and Simon, 1973a, 1973b; Frey and Adelman, 1976; Charness, 1976; Goldin, 1978). Chase and Simon added a significant contribution to DeGroot's results by finding no difference between players of varying ability for the recall of randomly placed pieces. Therefore, the experts' recall was not based on better memory, but their superiority was clearly chess-specific. Something about the organization of the chess position facilitated recall for the expert. Chase and Simon's work (1973a, 1973b) laid the foundation of the viewpoint others have called the "recognition-association model" (Hartston & Wason, 1984; Holding, 1985). Much of the research has focused on low level perceptual abilities. The model emphasizes the perception and encoding of chess positions in chunks which are grouping of related pieces. The relations within each chunk are chess-specific ones including proximity, defense, color, attack, and piece type. The expert's vast experience with chess positions leads to the development of a large number of these chunks stored in long term memory. As the player gains experience, the number and size of these chunks grows. According to the recognition-association model, labels associated with these chunks are held in short term memory and allow retrieval of the chunks from long term memory. This is why the expert recalls briefly presented positions better than the novice. The novice simply does not have the store of chunks available to him that the expert does. This also explains why

experts show no advantage for remembering random positions (Chase and Simon, 1973a; Frey and Adelman, 1976) because random positions are not made up of the chunks the expert can recognize. Random chunks are not part of the expert's chunk vocabulary in long term memory.

Through a computer simulation, Simon and Gilmarin (1973) have estimated a master-level player has from 10,000 to 100,000 of these patterns in long term memory. Access to this vast number of patterns explains his superior performance on memory tasks. Chase and Simon (1973b) also proposed a production system that uses perceptual chunking as its basis of cognitive organization that accounts for the experts' superior play. The vocabulary of chunks is associated with actions in terms of production rules. These rules associate chunks with specific actions (moves) and the system of chunk and production rules is more highly developed in higher skilled players. As a somewhat simplified example, consider that a player recognizes a chunk involving pieces A, B, and C in a specific configuration. This chunk may be associated with a specific move through a production rule like "if chunk ABC, then move X." This system explains how higher-rated players are able to select better moves which lead to superior play.

Problems with the Recognition-Association Model

Despite widespread acceptance of Chase and Simon's work, a number of researchers have discovered problems with the recognition-association model. The model has been weakened by a number of findings that have questioned the importance of chunking and its reliance on short term memory. For example, Charness (1976) found that recall for chess positions is minimally affected by use of 30 second interpolated tasks, and therefore, concluded that chess positions are in long term memory even after very brief presentations. Frey and Adelman (1976) conducted an experiment in which they found two consecutively presented chess positions could be remembered as well as

one, also leading them to suggest that brief presentations of chess positions are processed almost immediately into long term memory. Despite these problems with the theory, it has remained the generally-accepted view of memory for chess positions. It is regularly cited in articles (Ortega, 1989) and textbooks (Anderson, 1985; Best, 1989) in cognitive psychology without mention of the contrary findings.

There are several reasons this theory has survived despite contrary data. First, no alternative theory explains the data reported by Chase and Simon (1973b) as elegantly or at the same level of detail. Second, the argument that experts recognize familiar chunks of pieces and that the recognition of these chunks facilitates recall is compelling. This basic idea, that experts can recall domain-relevant material better than novices, and that they seem to recall the material using some type of chunking has been replicated in many other domains like bridge (Engle & Bukstel, 1978), Go (Reitman, 1976), the recall of electrical circuit diagrams (Egan & Schwartz, 1979), and the perception of musical notation (Sloboda, 1976). However, the critical thesis of the theory--that experts' superior recall results from their ability to recognize familiar configurations of pieces (chunks) and store their labels in short-term memory--must be reconciled with the empirical evidence that recall involves much more than short-term memory. This research examines the hypothesis that experts not only organize small groups of pieces into chunks, but also organize the chunks into a coherent and meaningful whole. Interestingly enough, in their original article, Chase and Simon (1973a) found that experts recalled somewhat more chunks than did novices. This finding was troubling (Simon & Chase, 1973) because a strict interpretation of a chunking hypothesis would predict the same number, but different sizes of chunks across skill levels (Miller, 1956). On this basis Chase and Simon (1973a) suggested that the experts' superiority "may derive from a hierarchical organization of the chunks, related to chess skill, that is more abstract than the simple chess relations we have measured." (p. 81) However, this possibility was

mentioned neither in the chapter they published later that year (Chase & Simon, 1973b) nor in their subsequent works.

The idea of an abstract organizational component to chess skill did not originate with Chase and Simon. Both Binet (1966) and Cleveland (1907) concluded that an ability to comprehend the board as a whole was vital to chess mastery. Unfortunately, these ideas of an overall component to the cognitive organization of chess positions have never been empirically demonstrated. Lane and Robertson (1979) did demonstrate a levels of processing effect for chess positions. Their subjects recalled positions better when they encoded them using a "deeper" level of processing by performing a meaningful task using the position than when they encoded the position by focusing on its physical characteristics. Lane and Robertson concluded that the overall organization present in a position assists experts in their recall, as did Egan and Schwartz (1979) in their study of memory for drawings of electrical circuits. However, both of these studies relied on indirect and anecdotal evidence to support this hypothesis.

An Alternative to the Recognition-Association Model

These experimental results imply a higher level process is involved in the perception, encoding, and recall of chess positions. After an extensive review of the literature, Holding also (1985) concluded that the organization of chess memory includes higher level components in addition to chunking. Even in Chase and Simon's original experiment the protocol of their master-level subject reveals a reliance on knowledge more abstract than chunks of chess pieces when he complains about "being unable to get the sense of the position" during brief presentations (Chase and Simon, 1973a).

Research from other domains also indicates a type of higher level cognitive organization involved in expert performance. Chi, Feltovich, and Glaser (1981) suggested, in their study of various levels of physics expertise, that experts encode

knowledge at a more abstract level than do novices. As previously mentioned, Egan and Schwartz (1979) found that experienced electricians used global cues in encoding circuit diagrams. Evidence for this was that experienced subjects were able to characterize an entire display after only a few seconds exposure. Chase and Simon's master reported a similar experience when he recognized a game from which the position had been taken within one second of exposure. Hartston and Wason (1984) report an unpublished study in which strong players were able to recognize positions as familiar within an average of 0.8 seconds of exposure. Egan and Schwartz called this ability to use global cues "conceptual chunking" in contrast to the "perceptual chunking" of Chase and Simon. Conceptual chunking explains skilled performance by the identification of an appropriate higher level concept associated with a position. The expert uses this higher level concept to organize and recall the position by systematically retrieving elements as chunks that are appropriate to the conceptual category identified. Also, by knowing the conceptual category the subject may be able to search the presented position more systematically. The conceptual chunking hypothesis offers an alternative to the recognition-association model of expert perception that incorporates more than perceptual chunking. The findings of Chase and Simon, while significant and influential, have tended to focus interest and research on perceptual chunking to the neglect of higher level processes which may be at work.

Empirical evidence of how higher level processing affects cognitive organization comes from the domain of verbal learning. Bransford and Johnson's work (1972) provides an example of how higher level knowledge affects cognitive processing during verbal comprehension. They showed context was vital to accurate recall of prose passages. Their subjects were given ambiguous passages of prose to read with a title either before, or after the reading. During recall the subjects who had been given the title prior to the reading of the passage performed significantly better than those who read the

title afterwards. A possible explanation of this performance difference is that the subjects in the topic-before group were able to encode the passage based on their knowledge of the topic and anticipated the structure or schemata of the subject matter. Therefore the topic-before group was able to employ this higher level cognitive organization in encoding the passage, whereas the topic-after group encoded the passage at a lower level.

Extending this notion to the domain of chess, we can explain the superior performance of master-level players during recall tasks by appealing to their ability to use higher-level cognitive organization as a strategy for encoding a position. Hartston and Wason (1984) have also commented that the recall of chess position for a master is similar to the ability of a person to understand a prose passage if given a title. This higher level cognitive model of encoding chess positions does not deny the existence of perceptual chunks. In fact, perceptual chunks are the essential building blocks of the higher level process. Appealing to a higher level organizing process shows how the perceptual chunks are woven together to create a whole. A test of experts' cognitive organization would be to present highly skilled players with positions, and a description of the position either before or after the position presentation. Better recall of those in the description-before condition would suggest that the players are using higher level information (the description) to recall a position. The recognition-association model cannot fully account for a difference between these two conditions because of its reliance on perceptual chunking. Superior recall in the description-before condition would indicate a reliance on more than perceptual chunking for recall. This would imply an ability to integrate the lower level perceptual chunks into a more coherent whole by using a higher level framework.

Experiment 1

Method

Subjects. Six rated chess players were recruited from the Houston Chess Studio and Rice University. Their ratings ranged from 1936 to 2314 with a mean of 2097. (See Appendix A for a discussion of the United States Chess Federation rating system.) Their ages ranged from 30 to 65 and their chess playing experience ranged from 12 to 53 years. Subjects were paid \$5.00 for participation.

Stimuli. Twelve positions and descriptions of those positions were developed by two USCF masters. The positions were quiescent (no exchanges in progress), early middle-game positions that contained the basic themes derived from a particular opening. The number of pieces in each position ranged from 25 to 32 pieces. The descriptions were brief (about two sentences) with information about the opening from which they derived and the basic plan for one or both sides. For example, the description of the position shown in Figure 1 was:

Sicilian-dragon with opposite-side castling. White is attacking the queenside. The other 11 positions and their respective descriptions are shown in the Appendix B.

Equipment. A Macintosh Plus computer was used for presenting the stimuli. The programming was done using HyperCard.

Procedure. Subjects were tested individually. Testing began by having the subjects read the instructions (which were presented on the computer) and observing a practice position to become familiar with the experimental format. Each subject saw the same twelve positions. The positions were divided into two sets of six (Set A and Set B). For half of the subjects, Set A was presented in the description-before condition, and Set B in the description-after condition. The sets were reversed for the other subjects. Trials alternated between those using description-before and those using description-after. In other respects, the assignment of specific positions to order of presentation was

randomized individually for each subject. The condition of the first trial was also determined randomly.

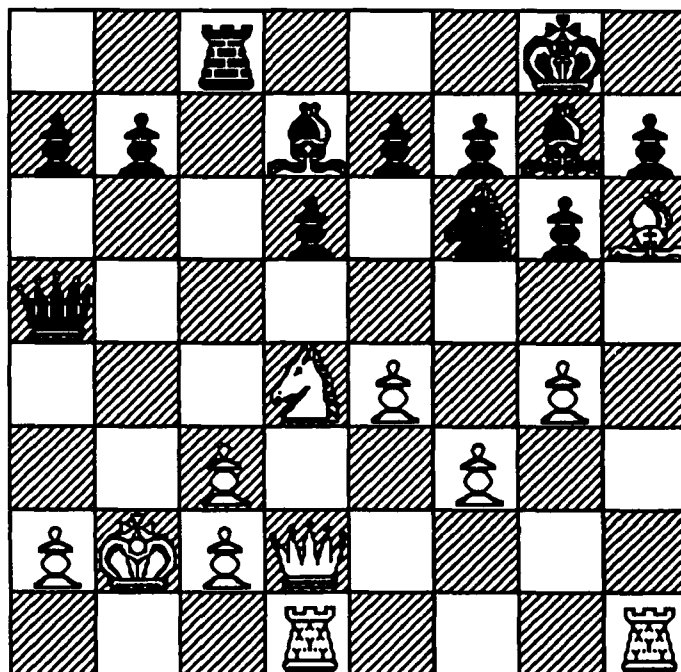


Figure 1. An Example of a Position Used in Experiments 1 and 2.

In the description-before condition, the descriptions were presented on the computer screen and subjects were given 20 seconds to read the description, after which the associated position was immediately presented. After the position was presented, subjects had to wait 20 seconds before beginning their recall. This 20 second period matched the time subjects in the description-after condition were shown the description.

Positions were presented four pieces at a time until all pieces had been shown. Each set of four pieces was randomly chosen (separately for each subject and without replacement), remained on the screen for five seconds, and was then erased and replaced by the next set of four pieces. The presentations continued until all the pieces making up the position had been shown. If the number of pieces in a position was not evenly divisible by 4, then fewer than 4 pieces were presented during the last presentation. After both the position and description were presented, the subject reconstructed the position using a chessboard placed adjacent to the computer. The experimenter provided the subject with only the pieces in the position. Subjects were instructed to place all pieces; if they couldn't recall a specific piece, they were instructed to guess. Subjects were allowed to use as much time as they wanted to reconstruct each position.

Positions were presented in unrelated groups to give the subjects' overall organization of the position a chance to manifest itself. It was expected that if the position were presented in its entirety, then even subjects in the position-after condition would be able to take advantage of the overall organization, since he or she would have been able to detect this organization very quickly, probably in less than one second, similar to the experience reported by the expert in Chase and Simon's original experiment. (Chase & Simon, 1973b) and to the ability reported by Hartston and Wason (1984).

Results

As can be seen in Table 1, all subjects performed better in the description-before than in the description-after condition. An analysis of variance showed this difference to be significant, $F(1,5)=9.60$, $p=.0267$. The description-before condition yielded higher scores for all six subjects.

Table 1. Percentage of Correctly Placed Pieces in Experiment 1

| | Description-Before | Description-After |
|-----------|--------------------|-------------------|
| Subject 1 | 86.1 | 67.7 |
| Subject 2 | 85.6 | 76.6 |
| Subject 3 | 89.6 | 86.7 |
| Subject 4 | 81.8 | 76.4 |
| Subject 5 | 95.3 | 93.2 |
| Subject 6 | 73.3 | 66.0 |
| Means | 85.3 | 77.8 |

$$F(1,5)=9.60, p=.0267$$

An analysis of variance was also performed to investigate the effects of position, i.e. were some positions easier than others? The results indicate that the positions did not differ significantly from one another, $F(11,55)=.363$, $p=.965$. An analysis of variance was also carried out to determine if there were any effects of presentation order, in other words, a learning effect or perhaps a fatigue effect. There were no significant effects of presentation order, $F(11,55)=.741$, $p=.695$. See Appendix E for detailed results of Experiment 1.

Discussion

The results of Experiment 1 could be questioned because of an artifact of the experimental design. During trials of the description-before condition, subjects read the description, saw the position, and then waited 20 seconds to begin recall. Presumably, they could have been rehearsing during the 20 second period, and this could account for their superior recall. During trials of the description-after condition, subjects had less

time for possible rehearsal because they were reading the description during the 20 second interval. Despite some evidence that interpolated tasks (the reading of the description can be considered to be an interpolated task) following position presentation have little effect upon recall (Charness, 1976), a more conservative test of the hypothesis would be to have subjects perform an interpolated task during the 20 second interval after position presentation in the description-before condition. In fact, such a design is particularly conservative because if rehearsal does have some effect, the description-after trials should benefit because most subjects did not require the full 20 second interval to read the description, and supposedly could be rehearsing during the remaining time. Experiment 2 added an interpolated task as a more conservative test of the hypothesis that a higher level process is involved in the perception and recall of chess positions.

Experiment 2

Method

Subjects. Eight rated chess players were recruited from the Houston Chess Studio. Their ratings ranged from 1412 to 2288 with a mean of 1871. Their ages ranged from 18 to 67 and their chess playing experience ranged from 6 years to 57 years. Subjects were paid \$5.00 for participation.

Stimuli. The positions and descriptions used were the same as in Experiment 1. In Experiment 1 subjects viewed a separate practice position, and saw 12 test positions. Two of the 12 positions from Experiment 1 were used as practice positions in Experiment 2 in order to give subjects practice under both test conditions. During the test phase of Experiment 2 each subject saw the same ten positions.

Equipment. Same as Experiment 1.

Procedure. The procedure paralleled that of Experiment 1 with the addition of an interpolated task. Subjects were required to count backwards by threes for 20 seconds

starting with a random three-digit number presented on the computer screen. The counting preceded position presentation in the description-after condition, and followed position presentation in the description-before condition. Therefore, the description-before condition consisted of:

- 1-position description
- 2-position presentation
- 3-interpolated task
- 4-recall

The description-after condition consisted of:

- 1- interpolated task
- 2-position presentation
- 3-position description
- 4-recall

Subjects were again given as much time as they wanted to reconstruct the positions, but recall times were collected in Experiment 2.

Results

The basic finding of Experiment 1, that the description-before condition leads to superior recall, was replicated. Table 2 shows that seven of eight subjects performed better in the description-before condition. An analysis of variance showed this difference to be significant, $F(1,7)=5.88$, $p=.046$.

Table 2. Percentage of Correctly Placed Pieces in Experiment 2

| | Description-Before | Description-After |
|-----------|--------------------|-------------------|
| Subject 1 | 77.7 | 65.5 |
| Subject 2 | 70.3 | 66.9 |
| Subject 3 | 92.2 | 82.8 |
| Subject 4 | 93.9 | 87.3 |
| Subject 5 | 69.8 | 82.1 |
| Subject 6 | 82.9 | 68.1 |
| Subject 7 | 88.8 | 73.2 |
| Subject 8 | 92.8 | 80.0 |
| Means | 83.6 | 75.7 |

$$F(1,7)=5.88, p=.0458$$

A serial position analysis was performed to check the effect of the counting backwards task. See Figure 2.

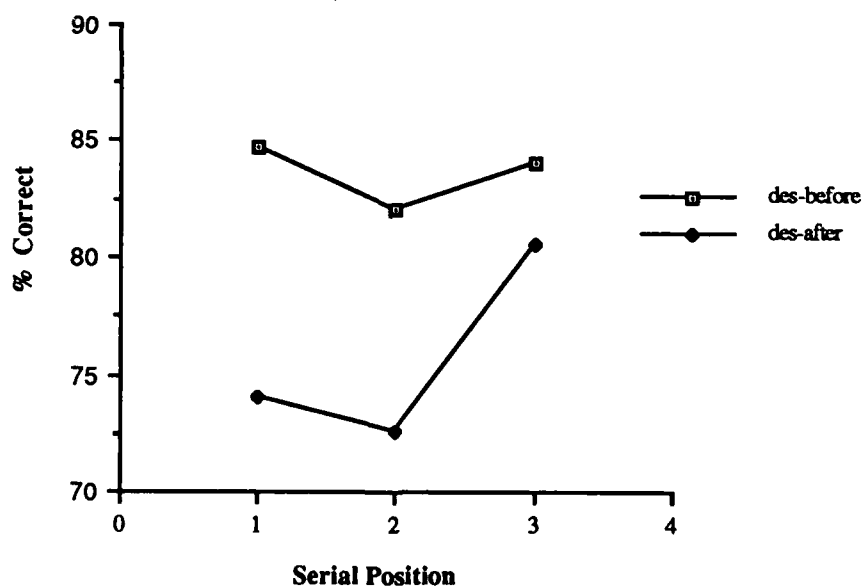


Figure 2. Experiment 2 Serial Position Effect

Pieces presented in the latter third of the position presentation were more likely to be correctly recalled in the description-after condition than in the first two-thirds of the presentation ($p=.04$). Note the improvement in the score for Serial Position 3 in the description-after condition. In contrast, in the description-before condition there was no effect of serial position ($p=.71$). This suggests subjects in the description-after condition may have been able to rehearse after reading the description, thus explaining their strong recency performance. Despite this advantage, the description-before condition showed superior recall.

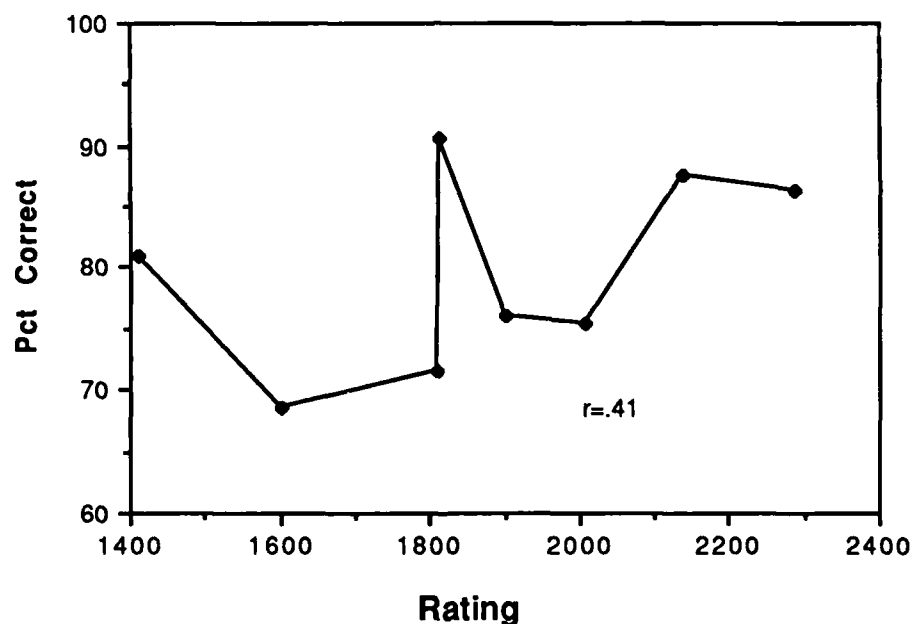


Figure 3. Exp 2: Correlation of Rating With Overall Performance

The correlation of chess rating with overall performance scores was not significant ($r=.41$, 6 df) because of the small sample size (with 6 df, $r \geq .71$ for significance), but the

trend is in the desired direction implying that performance on the task is dependent upon chess skill. See Figure 3.

Recall time was analyzed. There was no effect of condition on recall time ($p=.52$). The average time for recall for the description-before condition was 2 minutes, 52 seconds and the average for the description after was 2 minutes, 42 seconds. Time to recall was highly correlated with chess rating ($r=-.87$, $p<.01$). The higher the player was rated the less time it took to reconstruct the position. This also lends support to the idea that the task is dependent upon chess skill.

As in Experiment 1 an analysis of variance showed no effect of position ($p=.22$). In other words positions seemed to be of a uniform level of difficulty. Presentation order was also examined to see if there was any evidence of either learning or fatigue effects. An analysis of variance showed no effect of presentation order ($p=.88$). These results replicate the findings of Experiment 1. See Appendix F for detailed results of Experiment 2.

Discussion

The major finding of Experiment 1--that subjects are able to recall more in the description-before condition--was replicated in Experiment 2. The serial position analysis provided some evidence that the counting backwards task provided a conservative test of the hypothesis because it seemed to suppress the recency effect in the description-before condition, but not in the description-after condition. These results imply the recognition-association model does not fully account for the perception and recall of chess positions. A description presented prior to a position apparently aids the expert in recall more than the position presented afterwards. The description allows the expert to integrate the subsequent material better and facilitates his cognitive organization of the subsequent material. The results of the serial position analysis also suggest

subjects during the description-before condition may have been recalling the position as a whole because their performance was consistent across the three serial positions. In contrast, the superiority of the recency portion of the serial position curve during the description-after condition suggests subjects may have been using a low level strategy like recalling the last few pieces without integrating them into the position as a whole.

The first two experiments demonstrated the influence of a higher level concept like a description on the recall of a chess position. The experimental paradigm used to demonstrate this differed from previous research on chess perception by using a verbal description of a position. Previous research has used only the positions themselves as stimuli. If the hypothesis is correct that the expert is using higher level organizational cues that are inherent in the position, this organization should be able to manifest itself without the aid of a verbal description. Experiment 3 was designed to see if experts can perceive chess positions by using an organization that is not based on chunking.

Verbal descriptions as used in Experiments 1 and 2 are examples of a cognitive organization that is not based on chunks. Another possible cognitive organization of a chess position that is not based on chunks is the pawn structure. The chess literature is filled with accounts of the importance of pawns and the pawn structure. Kotov (1971) discusses the significance of the pawn structure by quoting Philidor (a noted 18th century player) who said "pawns are the soul of chess." (p.104) Other chess writers have commented that novice players tend to underestimate the true value of the pawn structure. Abrahams (1968) emphasizes that the pawn structure is independent of tactical analysis in terms of importance. Euwe (1953) stated that if a master were asked to evaluate a game in progress the first thing he would do would be to count the pawns. Psychologists writing on chess have also commented that pawn structure is critical in the master's choice of move (Hearst, 1977). Computer chess programs also use pawn structure to evaluate positions and plan moves (Slate & Arkin, 1977). Clearly, pawn structure is

vitaly important and may be a defining feature of a chess position. Experiment 3 was designed to contrast the recall of positions presented by chunks with positions presented by pawn structure.

Experiment 3

Method

Subjects. Thirty subjects were recruited from Rice University and the Houston Chess Studio. Subjects were placed into one of three groups (10 subjects per group) based on their level of chess skill. Rated players (recruited from the Chess Studio) were placed in the expert group. Their ratings ranged from 1550 to 2282 with a mean of 1904. Their ages ranged from 25 to 68 and their chess playing experience ranged from 6 years to 58 years. All subjects in the expert group were male. The rated players were paid \$5.00 for participation. The remaining 20 subjects were Rice undergraduates who were placed into either the naive group (little or no knowledge about chess) or the novice group (understood the rules of chess and had played, but had no rating). The subjects were classified into groups based on their responses to a chess knowledge questionnaire (see Appendix D). The subjects in the naive group ranged in age from 19 to 35. The novices ranged in age from 18 to 22. All subjects in the expert group were male. There were two females in the novice group and the naive group was made up of all females. Subjects in the naive and novice groups received course credit for participation.

Stimuli. Ten different middle game positions were used in the task. The positions were the ones used by Charness (1974) in a dissertation experiment. The number of pieces in each position ranged from 20 to 30 pieces. One of the positions is shown in Figure 2. All 10 positions are described in Appendix C.

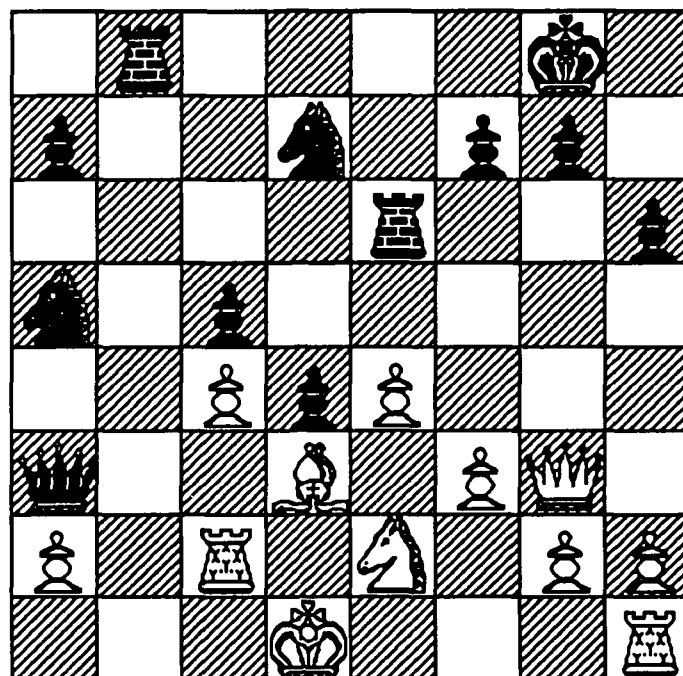


Figure 4. An Example of a Position Used in Experiment 3

Equipment. A Macintosh Plus computer was used for presenting the stimuli. The programming was done using HyperCard.

Procedure. Subjects were tested individually. Testing began by having the subjects read the instructions (which were presented on the computer) and observing two practice positions to become familiar with the experimental format. Each subject saw the same ten positions. Again, the positions were divided into two sets of six (Set A and Set B). For half of the subjects, Set A was presented in the chunk condition, and Set B in the pawn structure condition. The sets were reversed for the other subjects. Trials alternated between those using chunk and those using pawn structure conditions. In other respects, the assignment of specific positions to order of presentation was randomized individually for each subject. The condition of the first trial was also determined randomly.

In both conditions, positions were presented one piece at a time. One piece was presented, remained on the computer screen for approximately one second, and was immediately replaced by another piece. The difference between the conditions was that in the chunk condition, pieces were presented sequentially by chunk. Each piece was followed by a piece that was related to it by one of the Chase and Simon-defined relationships (Chase & Simon, 1973b) that hold chunks together (defense, attack, same color, etc.). The sequence was the same used by Charness (1974) in his dissertation experiment where he presented the same positions orally. The pawn structure condition merely presented all the pawns before presenting any major pieces. Pawns were presented "geographically" starting with White pawns on the lower left of the screen. (Refer to Figure 4 to understand how this was done.) All the White pawns in one column were presented, then the White pawns in the next column to the right were presented. After all the White pawns were presented, the Black pawns were presented, starting with the upper left of the screen and continuing column by column. Major pieces were then also presented "geographically" starting with the White pieces in the lower left of the screen.

After the position was presented subjects were asked to immediately recall the position as best they could by setting up the position on a chess board adjacent to the computer. The experimenter provided the subject with only the pieces in the position. Subjects were instructed to place all pieces; if they couldn't recall a specific piece, they were told to guess.

Results

An analysis of variance (three levels of expertise were analyzed as a between factor and two conditions as a within factor) revealed no reliable differences in recall scores between the positions presented by chunk and the positions presented by pawn structure. This result is shown in Table 3 and in Figure 5.

Table 3. Percentage of Correctly Placed Pieces in Experiment 3

| <u>Skill Level</u> | <u>Chunks</u> | <u>Pawn Structure</u> |
|--------------------|---------------|-----------------------|
| Naive | 33.1 | 33.4 |
| Novice | 44.9 | 48.8 |
| <u>Expert</u> | <u>64.6</u> | <u>62.7</u> |
| Means | 47.5 | 48.3 |

Main Effect of Chunk vs Pawn: $F(1,27)=.24$, $p=.6313$

Main Effect of Expertise: $F(2,27)=17.73$, $p<.0001$

There was a significant main effect of expertise. A subsequent Neuman-Keuls test indicated each level of expertise was reliably different from the others ($p<.05$). The interaction of expertise and condition was not significant $F(2,27)=1.13$, $p=.338$. The overall task is obviously dependent upon chess skill. The expert's ratings were correlated with overall performance as further evidence that the task is dependent upon chess skill. See Figure 6. As in Experiment 2, the correlation was not statistically significant ($r=.48$, 8 df) because of the small sample size, but was in the right direction.

Reconstruction time was analyzed with no main effect of condition $F(1,27)=1.25$, $p=.377$, and no main effect of expertise $F(2,27)=1.25$, $p=.303$.

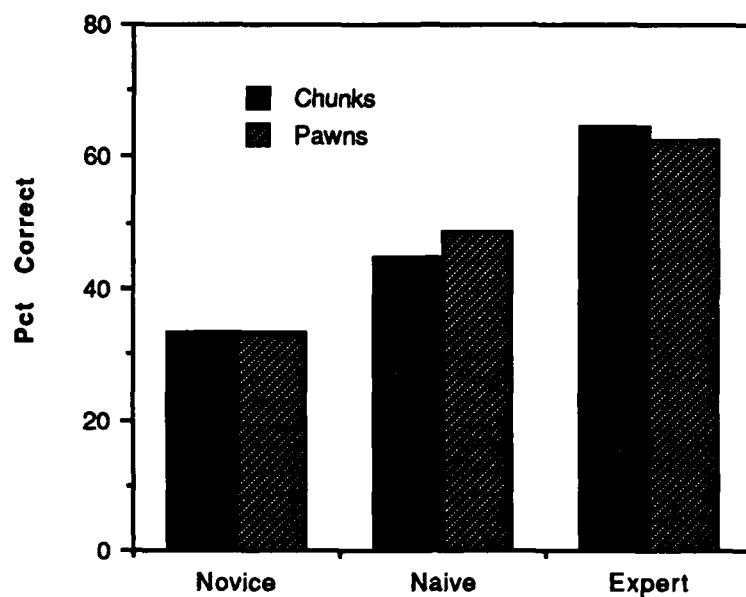


Figure 5. Comparison of Chunks vs Pawns

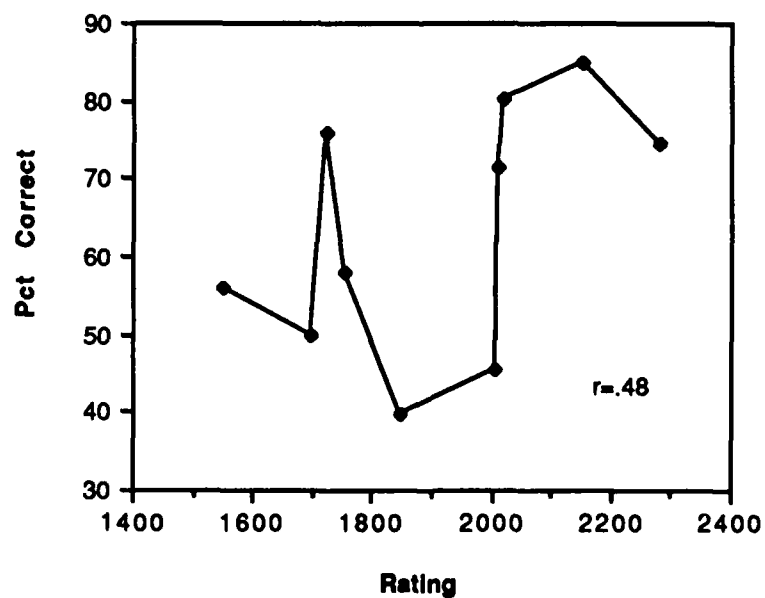


Figure 6. Exp 3: Correlation of Rating With Overall Performance

A serial position analysis was performed to investigate differences between the conditions. Because the test positions had from 20 to 30 pieces in them, serial positions were collapsed proportionately into 7 serial positions so all ten positions could be combined into one serial position curve. Figure 7 shows the results of the serial position analysis by expertise collapsed across the two conditions. Figure 7 confirms the effect of expertise and illustrates primacy and recency effects for all levels of expertise.

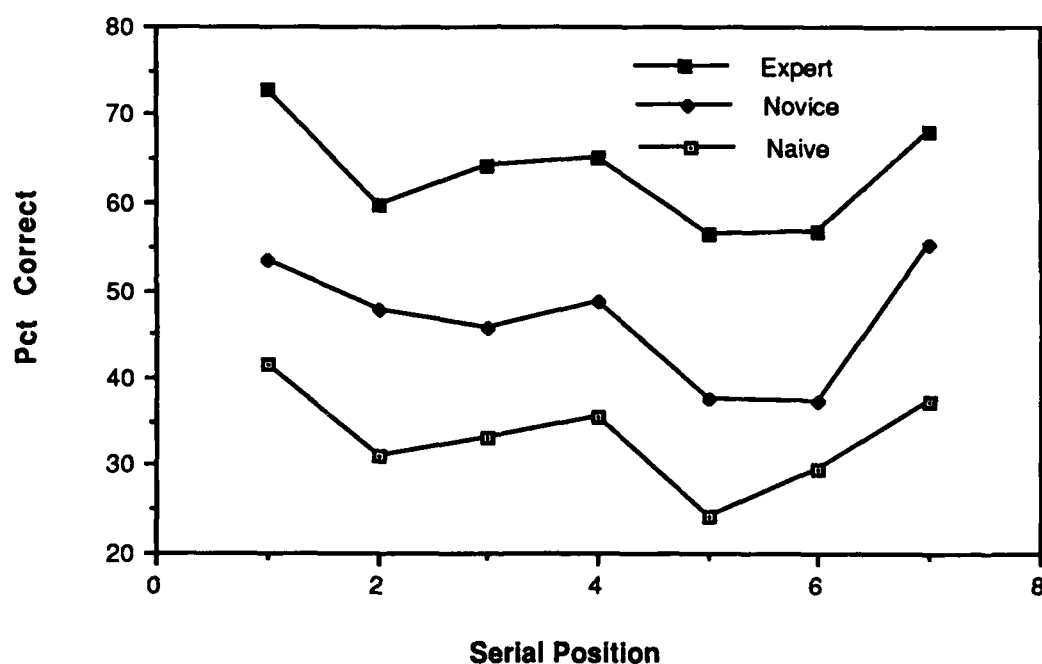


Figure 7. Exp 3: Serial Position Effect Across Conditions

An analysis of variance with 3 levels of expertise (between factor), 2 conditions (within factor), and 7 serial positions (within factor) confirmed the previous analysis by showing a main effect of expertise, but no main effect of condition. There was a main effect of serial position $F(6,162)=16.054$, $p<.0001$. The only significant interaction was

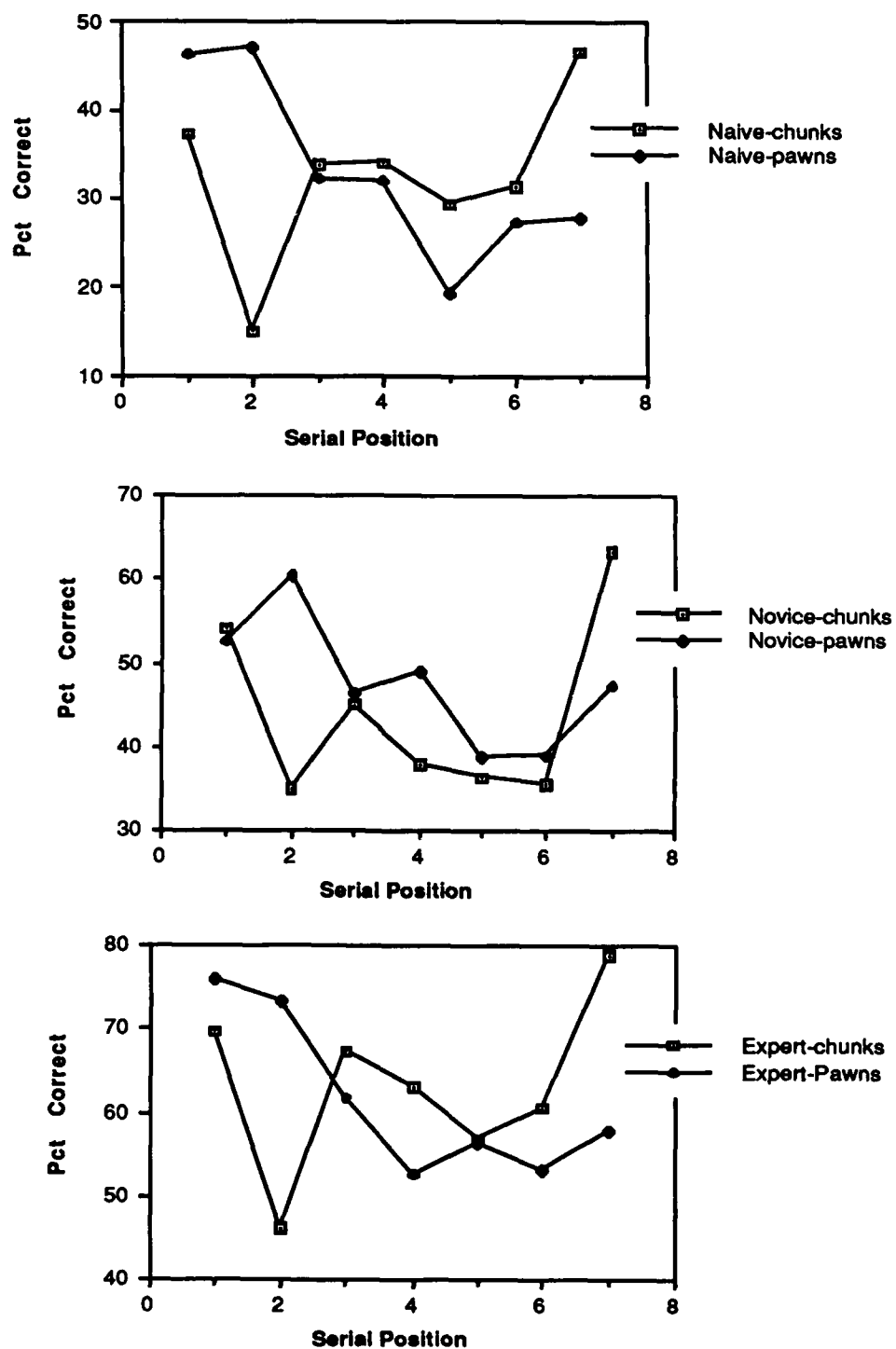


Figure 8. Exp 3: Serial Position Effect Chunk vs Pawn by Expertise

the condition x serial position interaction $F(6,162)=16.777$, $p<.0001$. Figure 8 depicts the serial position effects for each condition by expertise. Inspection of Figure 8, and an analysis of simple effects shows that the pawn structure condition is reliably different from the chunk condition at serial position 2 ($p<.0001$) and at serial position 7 ($p<.0001$). The pawn structure condition was superior in the primacy portion of the serial position curve across all three levels of expertise, and the chunk condition was superior in the recency portion for all levels of expertise.

Analysis of the effect of different positions showed that some positions were easier than others, but since subjects saw all the positions and the conditions were counterbalanced, this should not have affected the results. There was also an effect of presentation order, but this wasn't consistent across expertise nor did it indicate any learning or fatigue effects. See Appendix G for detailed results of Experiment 3.

Discussion

The most important finding of Experiment 3 was that recall of chess positions presented by pawn structure did not differ reliably from recall of positions presented by chunk. This implies pawn structure (at least in this specific task) aids the expert's cognitive organization as much as chunking does. The evidence in support of pawn structure is particularly striking because of the "geographic" method of presentation. This was essentially a columnar presentation with the pawn structure presented first. Previous research (Frey & Adelman, 1976; Charness, 1974) has compared column, chunked, and random presentations. Both of these earlier studies found chunked presentation to be the best, random the worst, and columnar between the two. The differences between all three conditions were significant. Apparently in Experiment 3 something about the pawn structure itself enhanced recall because a prediction based on previous research may have favored the chunked presentation. Of course, other reasons chunking may not have been

significantly better than pawn structure include power, differences between positions, and presentation order effects.

The serial position offers intriguing results. The fact that recall of the chunked positions show a strong recency effect may suggest that chunked positions are not recalled as a whole, what is recalled are groups of chunks and it is easier for the subject to recall the last chunks presented. The positions presented by pawn structure may have been integrated into a whole better and subjects tend to recall more pieces presented earlier. A problem with the interpretation of the serial position effect is that for the pawn structure condition, serial position is confounded with piece type. All the pawns were presented first, so the recency portion of the curve is made up exclusively of pawns. For the chunk condition, pieces and pawns are mixed during the presentation.

General Discussion

The serial position analysis points to an interesting parallel between Experiments 2 and 3. Both experiments resulted in a strong recency effect for positions encoded without the aid of a higher level organizing principle. See Figures 2 and 8. The positions where a higher level strategy was available, the description-before condition in Experiment 2 and the pawn structure condition in Experiment 3, showed no significant recency effects. This difference may be due to recall strategies available to the subject based on how the position was encoded. If the position integrated as a whole, recall may not show a recency effect. However, encoding at a lower level, that of perceptual chunks, may produce serial position curves more like the learning of lists of unrelated words. A possible test of this would be to add an interpolated task to the design of Experiment 3. Recall for positions encoded by pawn structure, or some other abstract organization, may be less affected by the task than recall of positions encoded by chunk. Recall of positions presented in their entirety are little affected by interpolated tasks (Charness, 1976; Frey &

Adesman, 1976). Experts seem to be able to use the global cues to encode the positions very rapidly. This is consistent with the idea that the pieces are organized into chunks with the chunks themselves organized at a more abstract level. The abstract organization provides very strong cues about the chunks present in a position and their relations to each other. These global cues make recall much less susceptible to decay and/or interference. If this higher level abstract organization is not available (as it may not be in a sequential chunked presentation) the expert may not be able to depend on these strong cues and may fall back on a lower level recall strategy. If, however, higher level abstract organization is important then recall of positions encoded by pawn structure should parallel the results of positions encoded in their entirety. Therefore the addition of an interpolated task may affect recall of the recency portion of the chunked presentation more than the pawn structure presentation.

These three experiments show that the recognition-association model cannot fully account for the expert's perception and recall of a chess position. The results indicate that a higher level of cognitive organization than the perceptual chunk is important in perception and recall. This more abstract level of organization allows the expert to integrate the chunks in a position. Examples of this type of organization are the description of a position as used in Experiments 1 and 2, and pawn structure as used in Experiment 3.

One important implication of these findings is that Simon and Chase's (1973) widely-cited estimate of 50,000 as the number of patterns stored in a chess master's long-term memory may be too high. The more the higher-level representations of positions are involved in encoding and reconstructing positions, the greater the overestimation of the number of chunks needed to reach a given level of recall. A second implication is that the importance of low-level chunks may have been overstated. Simon and Chase's contention that practice is the way to become a master is certainly correct

(Simon & Chase, 1973), but their ideas about what that practice does may be in error. While building a vocabulary of chunks and production rules is probably important, at least to a point, maybe the key to expertise is the development of higher level abstract organizing principles that allow the expert to integrate the chunks and production rules. A large vocabulary of chunks is critical, but without an ability to organize and integrate them increases in skill are limited.

References

- Abrahams, G. (1968) 3rd ed.). The Chess Mind (3rd ed.). London: Penguin.
- Anderson, J. R. (1985). Cognitive Psychology and Its Implications. New York: W. H. Freeman.
- Best, J. B. (1989) (2nd ed.). Cognitive Psychology. St. Paul, MN: West Publishing.
- Binet, A. (1893/1966). Mnemonic virtuosity: A study of chess players. Genetic Psychology Monographs, 74, 127-162. Originally published as "Les Grandes Mémoires: Résumé d'une Enquete sur les Joueurs d'Echecs" in Revue des Deux Mondes, 1893, 117, 826-859.
- Bransford, J.D., & Johnson, M.K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. Journal of Verbal Learning and Verbal Behavior, 11, 717-726.
- Charness, N. H. (1974) Memory for chess positions: The effects of interference and input modality. Dissertation Abstracts International, 35, 1933B (University Microfilms Order No. 74-23,346).
- Charness, N. (1976). Memory for chess positions: Resistance to interference. Journal of Experimental Psychology: Learning and Memory, 2, 641-653.
- Charness, N. (1981). Search in chess: Age and skill differences. The Journal of Experimental Psychology: Human Perception and Performance, 7, 467-476.
- Chase, W.G., & Simon, H.A. (1973a). Perception in chess. Cognitive Psychology, 4, 55-81.
- Chase, W.G., & Simon, H.A. (1973b). The mind's eye in chess. In W.G. Chase (ed.), Visual Information Processing (pp.215-281). New York: Academic Press.
- Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.
- Cleveland, A. A. (1907). The psychology of chess and learning to play it. American Journal of Psychology, 18, 269-308.
- DeGroot, A.D. (1965). Thought and Choice in Chess. The Hague: Mouton.
- DeGroot, A. D. (1966). Perception and memory versus thought: Some old ideas and recent findings. In B. K. Kleinmuntz (Ed.), Problem Solving (pp. 19-50). New York: Wiley.
- Duncker, K. (1945). On problem solving. Psychological Monographs, 58, No. 270.

- Egan, D. E. & Schwartz, B. J. (1979). Chunking in recall of symbolic drawings. Memory and Cognition, 7, 149-158.
- Elo, A.E. (1978). The Rating of Chessplayers. Past and Present. New York: Arco.
- Engle, R.W., & Bukstel. (1978). Memory processes among bridge players of differing expertise. American Journal of Psychology, 91, 673-689.
- Euwe, M. (1953). Judgment and Planning in Chess (trans. J. duMont). New York: David McKay.
- Frey, P. W., & Adesman, P. (1976). Recall memory for visually presented chess positions. Memory and Cognition, 4, 541-547.
- Goldin, Sarah E. (1978). Memory for the ordinary: Typicality effects in chess memory. Journal of Experimental Psychology: Human Learning and Memory, 104, 605-611.
- Hartston, W. R., & Wason, P. C. (1984). The Psychology of Chess. New York: Facts on File Publications.
- Hearst, E. (1977). Man and machine: Chess achievements and chess thinking. In P. W. Frey's (ed.) Chess Skill in Man and Machine. Springer-Verlag: New York.
- Holding, D. H., & Reynolds, R. I. (1982). Recall or evaluation of chess positions as determinants of chess skill. Memory and Cognition, 10, 237-242.
- Holding, D. H. (1985). The Psychology of Chess Skill. Hillsdale, NJ: Lawrence Erlbaum.
- Kotov, A. (1971). Think Like a Grandmaster (trans. B. Cafferty). London: B. T. Batsford.
- Lane, D. M. & Robertson, L. (1979). The generality of the levels of processing hypothesis: An application to memory for chess positions. Memory and Cognition, 7, 253-256.
- Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. Science, 208, 1335-1342.
- Luchins, A. S. (1942). Mechanization in problem-solving: The effect of Einstellung. Psychological Monographs, 54, No. 248.
- McKeithen, K. B., Reitman, J. S., Rueter, H. H., & Hirtle, S. C. (1981). Knowledge organization and skill differences in computer programmers. Cognitive Psychology, 13, 307-325.
- Miller, G. A. (1956). The magical number seven plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

- Ortega, K. A. (1989). Problem-solving: Expert/novice differences. Human Factors Society Bulletin, 32, 1-5.
- Reitman, J. S. (1976). Skilled perception in Go: Deducing memory structures from inter-response times. Cognitive Psychology, 8, 336-356.
- Shannon, C. E. (1950). Programming a computer for playing chess. The Philosophical Magazine, 41, 256-275.
- Shneiderman, B. (1976). Exploratory experiments in programmer behavior. International Journal of Computer and Information Sciences, 5(2), 123-143.
- Simon, H. A., & Newell, A. (1958). Heuristic problem solving. Operations Research, 6, 1-10.
- Simon, H. A. & Chase, W. G. (1973). Skill in chess. American Scientist, 61, 394-403.
- Simon, H. A. & Gilmarin, K. (1973). A simulation of memory for chess positions. Cognitive Psychology, 5, 29-46.
- Slate, D. J. & Arkin, L. R. (1977). Chess 4.5--The Northwestern University chess program. In P. W. Frey's (ed.) Chess Skill in Man and Machine. Springer-Verlag: New York.
- Sloboda, John A. (1976). Visual perception of musical notation: Registering pitch symbols in memory. Quarterly Journal of Experimental Psychology, 8, 1-16.
- Worsley, M., Johnston, W. A., & Simons, M. A. (1988). The influence of expertise on X-ray image processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14, 553-557.

Appendix A

The Elo rating system, used by both the World Chess Federation (FIDE) and the United States Chess Federation (USCF), was developed by the statistician Arpad Elo (Elo, 1978). Its statistical basis leads to accurate match and tournament prediction, and also allows precise rating adjustments based on performance. The ratings are a numerical system in which differences in rating may be converted into scoring/winning probabilities, and scoring percentages may be converted into rating differences. The rating system is an interval scale that assumes a normal distribution of chess skill. The following ratings define the various rankings used in chess:

| | |
|------------|---|
| 2600 | World Championship Contenders |
| 2400 | Most Grandmasters/International Masters |
| 2200 | Most National Masters |
| 2000 | Candidate Masters, Experts |
| 1800 | Amateur, Class A/Category 1 |
| 1600 | Amateur, Class B/Category 2 |
| 1400 | Amateur, Class C/Category 3 |
| 1200 | Amateur, Class D/Category 4 |
| Below 1200 | Novices |

The Elo system was designed for a rating of 1500 to be the average of all rated players. A 200 point difference corresponds to a standard deviation of chess skill. The normal distribution can then be used to predict the outcome of matches. For example, a 300 point difference between players will result in the higher-rated player winning 85% of the time; a 100 point difference will result in the higher-rated player winning 64% of the time; a 600 point difference favors the higher-rated player 98% of the time. If tournament or match play results do not correspond closely with the predictions based on the participants' ratings, the ratings are appropriately adjusted to reflect their actual performance. This adjustment mechanism keeps ratings current. The accuracy of rating,

prediction, and system of rating adjustment leads to much more precisely defined levels of expertise than in most domains, making chess an excellent domain for studying expertise.

Appendix B

Positions Used in Experiments 1 and 2:

Position 1: King's Indian. White seeks queenside breakthrough, Black attacks on the kingside. Position in Forsyth¹ notation.

r1b3k1,pppnq1bp,3p1r2,2PPp1pn,1P2Pp2,2NN1P2,P3BBPP,R2Q1RK1¹

Position 2: Queen's Gambit Declined Exchange Variation-type position. White is conducting a minority attack. Black has defensive resources and some prospect of a kingside attack.

r3rnk1,1p1bqpp1,p1p4p,3p4,1P1Pn3,2N1PN2,P1Q1BPPP,1RR3K1

Position 3: Benoni-like position. White prepares central break. Black counterattacks on the queenside and threatens White's King Pawn.

1r1qr1k1,1pnb1pbp,p2p2p1,2pPP3,P4Pn1,2N2N2,1P2B1PP,R1BQ1R1K

(used as a practice position in Experiment 2)

Position 4: Queen's Gambit Declined-type position. White tries to exploit the weakness of Black's Queen Bishop Pawn and keep Black cramped. Black tries to achieve a freeing push of his Queen Bishop Pawn.

2r2rk1,pb1nqpp1,1pp1p2p,8,1P1PB3,1Q2PN2,P4PPP,1RR3K1

Position 5: Scheveningen Sicilian-type position. White is attacking the kingside, and Black is counterattacking on the queenside and against White's King Pawn.

2rr2k1,1b1nbppp,p2ppn2,qp6,3NPP2,P1N1BBQ1,1PP3PP,R4RK1

¹ In Forsyth notation, capital letters represent white pieces and small letters black pieces. Numbers represent blank spaces. Each of the eight units, separated by commas, represents a rank (row), beginning with the eighth. the notation "2r3k1,pp1bpbp;" is short for "Eighth Row: skip 2 spaces, black rook, skip 3 spaces, black king, skip 1 space; Seventh Row: 2 black pawns, skip 1 space, black bishop, 2 black pawns, black bishop, black pawn."

Position 6: Nimzo-Indian Saemisch-type position. White is attacking on the kingside.

Black is counterattacking against White's weak pawns on the queenside.

r3r1k1,p1q2ppp,bp1ppn2,n1p5,1PPP1P1,P1PB1PN1,Q6P,R1B2RK1

Position 7: Panov-Botvinnik Caro-kann type position. White advancing queenside pawn majority. Black is adopting a passive defense.

1r1q1rk1,p2bbppp,2p1pn2,2PpN3,1P1P4,2NQ4,P4PPP,1RB1R1K1

Position 8: Ruy Lopez Exchange Variation-type position. White plays for an ending in which he advances his kingside pawn majority. Black strives for counterplay with his two bishops and active pieces.

2krr3,1ppb1ppp,p1pb1n2,8,4P3,2NNBP2,PPP3PP,R4RK1

Position 9: Dutch Defense-type position. White is playing passively. Black is attacking on the kingside.

5rk1,pppbbr1p,2nppn2,5ppq,2PP4,1PN1P1P1,PBQ1NPBP,5RRK

Position 10: Sicilian-dragon with opposite side castling. White is attacking the kingside, Black the queenside.

2r3k1,pp1bppbp,3p1npB,q7,3NP1P1,2P2P2,PKPQ4,3R3R

Position 11: Slav Defense to the Queen's Gambit Declined. White plays to exploit Black's weakness on the dark squares. Black plans to utilize his queenside pawn majority.

rmlqk2r,1b3ppp,p1pBp3,1p1nP3,P2P4,5NP1,5PBP,R2Q1RK1

(used as a practice position in Experiment 2)

Position 12: Morra Gambit-type position. White using space advantage and open lines against Black's center pawns and kingside. Black defending passively hoping to exploit pawn advantage in the endgame.

r2rn1k1,1p1bbppp,pqnpp3,6N1,4PB2,1BN5,PP1RQPPP,2R3K1

Appendix C

Positions Used in Experiment 3:

Position 1: 1r4k1,p2n1pp1,4r2p,n1p5,2PpP3,q2B1PQ1,P1R1N1PP,3K3R

(Positions are given in Forsyth notation. See Appendix B for an explanation.)

Position 2: r3Q3,pp3rkp,2n3p1,3pR3,3p1qq1P,1N1B1N1b,PPP2PP1,R5K1

Position 3: 3rrbk1,p1q2ppp,1pb1pn2,8,2P2P2,2BP2P1,P3QN1P,1BR2RK1

Position 4: r2r1bk1,1b2q1pp,1nnp1p2,p3pN2,Pp1PP3,1P1B1N1P,1B1Q1PP1,
2R1R1K1

Position 5: r1r1nbk1,2qb1ppp,p2p4,6B1,Pp1NP3,1B5P,1P3PP1,R2QR1K1

Position 6: r4r1k,6pp,p2NQnn1,q7,B1PP4,B5P1,P4P1P,5RK1

Position 7: r2r2k1,p3bpp1,bpq1pn1p,8,1pP3B,P1N5,1P2QPPP,1B1RR1K1

Position 8: rn3k2,1R3ppp,p2p4,3Pp3,4P1n1,2q2N2,P1B1bPPP,1Q4K1

Position 9: r2r1nk1,ppq1p1b1,2p2pp1,5P2,1P1P1n2,4B1N1,PQ2P1BP,2RR2K1

Position 10: r5k1,r1bR1ppp,pp2p3,8,1PP1PP2,4B1P1,7P,R4K2

Appendix D

Questionnaire (Experiment 3)

Name _____

Sex ____ Age ____

Basic Knowledge:

Do you know the basic rules of chess:

- how to set up the pieces Yes/No
- how all the pieces move Yes/No
- what determines a check Yes/No
- what determines a checkmate Yes/No
- how to castle Yes/No

-if you answered no to any of the above you don't have to answer the remaining questions

Advanced Knowledge:

Do you know

- what a fianchettoed position is Yes/No
- how to describe a Sicilian Defense Yes/No
- what a doubled pawn is Yes/No
- what a fork is Yes/No
- what en prise Yes/No
- what constitutes a stalemate Yes/No

Chess Playing Activity:

How long have you known the rules (yrs)? _____

Describe your playing activity. Ex- I play about once a month.

Ex- I played in high school in a club.

Have you ever read a book about improving your chess play? Yes/No

Appendix E

Experiment 1 raw data/ea. line is a subject/12 pos'n scores:

62.5, 85.7, 70, 88.5, 66.7, 80, 57.1, 76.9, 68.7, 96, 81.5, 89.7
 96.9, 64.2, 90, 80.8, 86.7, 93.3, 75, 69.2, 87.5, 66, 77.8, 86.2
 93.7, 85.7, 93.3, 92.3, 96.7, 93.3, 78.6, 88.5, 87.5, 88, 70.4, 89.7
 81.2, 71.4, 71.4, 69.2, 90, 76.7, 82.1, 80.8, 84.4, 88, 81.5, 72.4
 100, 100, 96.7, 92.3, 90, 86.7, 96.4, 96.2, 90.6, 100, 85.2, 96.5
 75, 71.4, 60, 65.4, 83.3, 60, 78.6, 80.8, 68.8, 60, 74.1, 58.6

Subject Ratings:

1-2139

2-2314

3-1936

4-1991

5-2250

6-1952

Avg: 2097

Averages: Des-Bef/Des-Aft/Overall/By Subject:

86.1, 67.7, 76.9

85.6, 76.6, 81.1

89.6, 86.7, 88.1

81.8, 76.4, 79.1

95.3, 93.2, 94.3

73.3, 66.0, 69.7

Effect of Condition:

| Source | df | SS | MS | F | p |
|----------|----|---------|---------|-------|-------|
| Subjects | 5 | 748.568 | 149.714 | | |
| c | 1 | 169.501 | 169.501 | 9.640 | .0267 |
| Error | 5 | 87.914 | 17.583 | | |

Avg Description-Before: 85.3

Avg Description-After: 77.8

Effect of Position:

| Source | df | SS | MS | F | p |
|----------|----|----------|---------|------|-------|
| Subjects | 5 | 4470.719 | 894.144 | | |
| p | 11 | 346.948 | 31.541 | .363 | .9650 |
| Error | 55 | 4782.229 | 86.950 | | |

Position Means

| | |
|------|---------|
| p 1 | 84.8833 |
| p 2 | 79.7333 |
| p 3 | 80.2333 |
| p 4 | 81.4167 |
| p 5 | 85.5667 |
| p 6 | 81.6667 |
| p 7 | 77.9667 |
| p 8 | 82.0667 |
| p 9 | 81.2500 |
| p 10 | 83.0000 |
| p 11 | 78.4167 |
| p 12 | 82.1833 |

Effect of Presentation Order:

| Source | df | SS | MS | F | p |
|----------|----|----------|---------|------|-------|
| Subjects | 5 | 4905.572 | 981.114 | | |
| o | 11 | 1294.352 | 117.668 | .741 | .6952 |
| Error | 55 | 8737.759 | 158.868 | | |

Presentation Order Means

| | |
|--------|---------|
| ord 1 | 74.5000 |
| ord 2 | 72.9333 |
| ord 3 | 81.0500 |
| ord 4 | 82.3167 |
| ord 5 | 74.8667 |
| ord 6 | 79.8667 |
| ord 7 | 78.9000 |
| ord 8 | 84.8167 |
| ord 9 | 83.2667 |
| ord 10 | 85.4333 |
| ord 11 | 86.0667 |
| ord 12 | 82.1000 |

Appendix F

exp 2 raw data/ea. line is a subject/2 prac & 10 pos'n scores:

46.7 81.5 53.1 85.7 62.1 73.1 66.7 53.3 64.3 88.5 81.2 88.0
 73.3 77.8 68.8 57.1 69 69.2 66.7 66.7 75.0 65.4 71.9 76
 80 88.9 93.8 92.9 79.3 88.5 83.3 83.3 85.7 96.2 71.9 100
 93.3 85.2 96.9 92.9 89.7 88.5 100 86.7 89.3 84.6 93.8 84
 50 74.1 81.2 78.6 82.8 65.4 73.3 60 85.7 76.9 87.5 68
 90 51.9 75 85.7 93.1 46.2 93.3 63.3 75 73.1 78.1 72
 73.3 77.8 71.9 82.1 82.8 92.3 83.3 73.3 50 96.2 78.1 100
 90 85.2 90.6 82.1 100 88.5 100 68.8 85.7 80.8 87.5 80

Subjects Ratings:

1-1811
 2-1600
 3-2139
 4-1814
 5-1900
 6-2007
 7-1412
 8-2288
Avg: 1871

Averages: Des-Bef/Des-Aft/Overall/By Subject

| | | |
|-------------|-------------|----------------------|
| 77.7 | 65.5 | 71.6 |
| 70.3 | 66.9 | 68.6 |
| 92.2 | 82.8 | 87.5 |
| 93.9 | 87.3 | 90.6 |
| 69.8 | 82.1 | 75.9 |
| 82.9 | 68.1 | 75.5 |
| 88.8 | 73.2 | 81.0 |
| <u>92.8</u> | <u>80.0</u> | <u>86.4</u> |
| 83.6 | 75.7 | 79.6-Averages |

Effect of Condition

| Source | df | SS | MS | F | p |
|----------|----|---------|---------|-------|-------|
| Subjects | 7 | 893.454 | 127.636 | | |
| c | 1 | 244.141 | 244.141 | 5.877 | .0458 |
| Error | 7 | 290.784 | 41.541 | | |

Effect of Position:

| SOURCE | DF | SS | MS | F | P |
|----------|----|----------|---------|-------|-------|
| Subjects | 7 | 5526.077 | 789.440 | | |
| p | 11 | 1640.419 | 149.129 | 1.323 | .2280 |
| Error | 77 | 8677.261 | 112.692 | | |

Means by Position:

| | |
|--------|---------|
| prac 1 | 74.5750 |
| prac 2 | 77.8000 |
| p 1 | 78.9125 |
| p 2 | 82.1375 |
| p 3 | 82.3500 |
| p 4 | 76.4625 |
| p 5 | 83.3250 |
| p 6 | 69.4250 |
| p 7 | 76.3375 |
| p 8 | 82.7125 |
| p 9 | 81.2500 |
| p 10 | 83.5000 |

Effect of Presentation Order:

| SOURCE | DF | SS | MS | F | P |
|----------|----|----------|---------|------|-------|
| Subjects | 7 | 5526.077 | 789.440 | | |
| order | 11 | 729.633 | 66.330 | .533 | .8753 |
| Error | 77 | 9588.046 | 124.520 | | |

Means for presentation order:

| | |
|---------|---------|
| prac 1 | 74.5750 |
| prac 2 | 77.8000 |
| posn 1 | 84.9125 |
| posn 2 | 79.1250 |
| posn 3 | 79.3875 |
| posn 4 | 79.3750 |
| posn 5 | 82.1750 |
| posn 6 | 75.2125 |
| posn 7 | 78.7750 |
| posn 8 | 79.0375 |
| posn 9 | 76.9250 |
| posn 10 | 81.4875 |

raw data for serial position:spl-des-1st/spl-posn-1st,etc

| | | | | | |
|------|------|------|------|------|------|
| 70 | 60 | 81.2 | 65.8 | 62.5 | 67.5 |
| 80 | 77.5 | 61.8 | 59.4 | 77.5 | 67.5 |
| 95 | 80 | 89 | 84.2 | 92.5 | 82.5 |
| 92.5 | 85 | 93.4 | 84.4 | 97.5 | 97.5 |
| 82.5 | 87.5 | 64 | 76.3 | 75 | 87.5 |
| 77.5 | 65 | 84.2 | 67.2 | 87.5 | 75 |
| 87.5 | 70 | 90.6 | 75 | 85 | 77.5 |
| 92.5 | 67.5 | 92.1 | 68.4 | 95 | 90 |

Serial Position Effect

| Source | df | SS | MS | F | p |
|----------|----|----------|---------|-------|-------|
| Subjects | 7 | 2761.233 | 394.462 | | |
| s | 2 | 204.698 | 102.349 | 1.605 | .2358 |
| Error | 14 | 893.029 | 63.788 | | |
| c | 1 | 737.117 | 737.117 | 6.789 | .0351 |
| Error | 7 | 759.975 | 108.568 | | |
| sc | 2 | 118.921 | 59.461 | 3.476 | .0595 |
| Error | 14 | 239.512 | 17.108 | | |

serial pos @ des-before $F(2,14) = .347, p = .713$
 serial pos @ des-after $F(2,14) = 3.994, p = .042$
 cond @ serial pos 1 $F(1,7) = 10.592, p = .014$
 cond @ serial pos 2 $F(1,7) = 5.697, p = .048$
 cond @ serial pos 3 $F(1,7) = 1.262, p = .298$

serial position:

| | | |
|------|----------|---------|
| sp 1 | | 79.3750 |
| sp 2 | | 77.3125 |
| sp 3 | | 82.3437 |
| sp 1 | des-1st | 84.6875 |
| sp 1 | posn-1st | 74.0625 |
| sp 2 | des-1st | 82.0375 |
| sp 2 | posn-1st | 72.5875 |
| sp 3 | des-1st | 84.0625 |
| sp 3 | posn-1st | 80.6250 |

Effect of Condition on Recall Time:

| SOURCE | DF | SS | MS | F | P |
|----------|----|------------|-----------|------|-------|
| Subjects | 39 | 527256.950 | 13519.409 | | |
| c | 1 | 2121.800 | 2121.800 | .406 | .5280 |
| Error | 39 | 204041.200 | 5231.826 | | |

| | |
|---------------------|----------|
| avg description 1st | 172 secs |
| avg position 1st | 162 secs |

Appendix G

Experiment 3 raw data/ea. line is a subject/2 prac, 10 pos'n/1st number is expertise/1-naive/2-novice/3-expert:

1,39.3,26.9,29.2,52,30.8,36.7,26.9,38.1,59.3,47.8,46.2,65
 1,25,23.1,37.5,44,23.1,20,23.1,19,29.6,30.4,34.6,35
 1,32.1,53.8,33.3,36,34.6,46.7,30.8,57.1,37,30.4,23.1,60
 1,10.7,26.9,20.8,24,26.9,23.3,19.2,23.8,25.9,26.1,26.9,45
 1,35.7,42.3,50,36,46.2,26.7,38.5,42.9,51.9,26.1,38.5,40
 1,42.9,38.5,33.3,52,42.3,43.3,30.8,47.6,44.4,43.5,34.6,60
 1,10.7,23.1,8.3,24,26.9,10,46.1,23.8,22.2,26.1,23.1,20
 1,25,30.8,29.2,24,57.7,23.3,26.9,33.3,48.1,39.1,26.9,30
 1,35.7,19.2,25,36,50,36.7,34.6,23.8,29.6,21.7,23.1,45
 1,7.1,15.4,29.2,16,23.1,20,15.4,19,18.5,21.7,34.6,25
 2,32.1,34.6,62.5,68,65.4,53.3,42.3,71.4,40.7,65.2,38.5,70
 2,71.4,46.2,45.8,60,42.3,56.7,65.4,66.7,51.9,39.1,38.5,60
 2,35.7,30.8,33.3,64,19.2,56.7,34.6,38.1,51.9,30.4,26.9,50
 2,35.7,11.5,8.3,44,26.9,30,30.8,38.1,37,21.7,38.5,50
 2,71.4,53.8,54.2,60,57.7,60,42.3,57.1,70.4,65.2,34.6,55
 2,46.4,50,45.8,44,50 53.3,42.3,42.9,77.8,60.9,61.5,80
 2,35.7,23.1,16.7,56,26.9,43.3,38.5,47.6,29.6,39.1,38.5,35
 2,46.4,53.8,41.7,48,50,40,69.2,42.9,44.4,56.5,50,70
 2,21.4,26.9,20.8,52,38.5,36.7,57.7,28.6,44.4,43.5,19.2,50
 2,46.4,53.8,29.1,36,53.8,40,46.1,66.7,48.1,47.8,4 6.1,45
 3,64.3,69.2,45.8,76,76.9,86.7,76.9,81,74.1,65.2,61.5,70
 3,71.4,46.2,54.1,68,69.2,46.7,57.7,66.7,66.7,56.5,34.6,40
 3,75,61.5,45.8,84,57.7,46.7,46.1,61.9,66.7,47.8,69.2,55
 3,85.7,84.6,75,80,76.9,83.3,69.2,76.2,77.8,60.9,84.6,75
 3,100,96.2,91.7,76,84.6,66.7,80.8,81,88.9,91.3,92.3,95
 3,75,88.5,70.8,100,80.8,76.7,69.2,95.2,74.1,87,69.2,80
 3,75,73.1,83.3,64,76.9,80,57.7,76.2,100,60.9,80.8,65
 3,39.3,57.7,29.2,52,53.8,50,42.3,71.4,55.6,34.8,53.8,55
 3,57.1,65.4,25,64,30.8,30,34.6,52.4,44.4,47.8,38.5,30
 3,42.9,38.5,50,44,61.5,63.3,30.8,42.9,40.7,56.5,30.8,35

Subject Ratings:

1-2009

2-1550

3-1756

4-1723

5-2150

6-2021

7-2282

8-1697

9-1848

10-2004Avg: 1904Averages:

chunks-47.5

pawns- 48.3

naive- 33.2

novice-46.8

expert-63.6

naive chunks- 33.1

naive pawns- 33.4

novice chunks-44.9

novice pawns- 48.8

expert chunks-64.6

expert pawns- 62.7

Effect of Condition:

| Source | df | SS | F | p |
|-------------|----|----------|-------|-------|
| group | 2 | 46265.93 | 17.73 | .0001 |
| Error | 27 | 35230.93 | | |
| cond | 1 | 43.62 | .24 | .6313 |
| group x con | 2 | 418.17 | 1.13 | .3381 |
| error | 27 | 4999.35 | | |

Summary Table of the Effect Time:

| Source | df | SS | MS | F | p |
|-------------|----|------------|----------|-------|-------|
| group | 2 | 16060.233 | 8030.117 | 1.250 | .3026 |
| Error | 27 | 173463.100 | 6424.559 | | |
| cond | 1 | 1197.067 | 1197.067 | .808 | .3767 |
| group x con | 2 | 904.433 | 452.217 | .305 | .7395 |
| Error | 27 | 40008.500 | 1481.796 | | |

naive 106.85 secs
 novice 144.40 secs
 expert 137.75 secs

chunks 134.13 secs
 pawns 125.20 secs

naive/chunks 106.2 secs
 naive/pawns 107.5 secs
 novice/chunks 149.7 secs
 novice/pawns 139.1 secs
 expert/chunks 146.5 secs
 expert/pawns 129.0 secs

Serial Position raw data/ea. line is a subject/1st number is
 expertise/serial pos 1-7 chunk/serial pos 1-7 pawn

1,15,20,31.6,51.6,35,36.6,71.6,68.4,78.4,30,63.4,27.2,48.4,23.2
 1,46.6,28.2,24,11.6,19,33.4,36.6,33.4,60,18.2,21.6,10,21.6,40
 1,20,23.4,54.8,48.4,28.2,16.6,30,71.8,56.6,31,44.8,33,56.6,31.8
 1,66.8,6.6,22.4,16.6,34,31.6,24.8,36.6,36.6,29.8,10,29.8,11.6,15
 1,26.6,20,58.4,51.6,33.2,55,70,46.8,40,34.8,58.4,17.4,26.6,25
 1,70,20,33.2,83.4,44,33.2,66.6,41.6,43.4,48.4,31.6,23.2,25,46.6
 1,25,0,23.4,31.6,23.2,15,55,26.6,55,15.6,18.4,6.6,18.2,6.6
 1,45.2,18.2,34,26.6,20.6,35,33.2,41.6,58.4,46.6,35,21.6,21.6,35
 1,36.6,10,21.6,25,31.8,36.6,63.4,63.4,10,40.4,38.4,18.2,28.2,30
 1,19.8,5,33,18.2,24,20,15,35,31.6,28.2,21.6,6.6,16.6,26.6
 2,38.4,43.4,51.6,71.6,28.2,41.6,70,90,76.8,71.4,61.8,61,23.2,70.2
 2,68.2,48.4,56,55,47,35,83.4,36.6,80,53.4,53.4,28.4,30,58.4
 2,43.4,15,25,36.6,23.2,20,65,81.6,68.4,43,24.8,23,54.8,36.6
 2,58.4,23.2,26.2,16.6,27.4,55,48.2,30,40,30,36.6,21.6,10,25
 2,53.4,25,75.2,68.4,25,31.6,85,70,75,43.4,66.8,52,60.2,46.6
 2,68.2,43.4,44,53.2,66,51.6,60,56.6,58.4,68.2,75,33.4,30,65
 2,70,63.2,56.4,43.2,13.2,33.2,53.2,36.6,45,5,31.6,38.4,0,51.6

2, 60, 43.4, 46.6, 38.2, 47, 55, 68.2, 63.4, 65, 65, 41.6, 41.8, 46.6, 35
 2, 36.6, 25, 30, 36.6, 53.4, 25, 46.6, 30, 61.6, 52, 48.4, 28.6, 41.6, 25
 2, 58.4, 11.6, 53, 66.8, 28, 41.6, 70, 31.6, 61.6, 46.6, 31.6, 35, 40, 61.6
 3, 66.6, 68.4, 76.6, 61.6, 55.2, 60, 58.4, 73.4, 100, 66, 80, 75.4, 61.6, 73.4
 3, 71.6, 16.6, 75, 66.8, 50.8, 45, 60, 80, 58.4, 61.8, 58.4, 43.4, 46.6, 46.6
 3, 51.6, 35, 51.6, 73.4, 46.6, 48.4, 90, 58.2, 90, 43.6, 63.4, 58, 48.2, 48.4
 3, 93.4, 55, 76.8, 78.4, 77.8, 70, 65, 100, 95, 81.8, 60, 53.4, 80, 68.4
 3, 95, 85, 88.4, 90, 85, 78.4, 95, 100, 71.6, 92, 88.4, 79.4, 73.4, 68.4
 3, 86.6, 83.4, 89.4, 95, 81.8, 83.4, 90, 85, 75, 68.2, 70, 71.8, 73.4, 66.6
 3, 80, 51.6, 75.2, 90, 75, 90, 95, 93.4, 86.6, 83.4, 63.4, 62.6, 38.4, 53.2
 3, 56.6, 33.2, 49.6, 65, 43, 50, 70, 58.4, 56.6, 35, 31.6, 29.8, 45, 66.6
 3, 26.6, 16.6, 33.2, 41.6, 30, 21.9, 73.4, 65, 56.6, 44, 33.4, 31.2, 34.8, 50.2
 3, 68.4, 15, 55.2, 43.4, 22, 56.6, 68.4, 45, 43.4, 41.6, 46.6, 54.8, 30, 36.6

Serial Position ANOVA:

| Source | df | SS | MS | F | p |
|-----------|-----|-----------|-----------|--------|-------|
| group | 2 | 63350.156 | 31675.078 | 17.501 | .0000 |
| Error | 27 | 48867.596 | 1809.911 | | |
| cond | 1 | .015 | .015 | .000 | .9941 |
| g x c | 2 | 95.083 | 47.542 | .177 | .8387 |
| Error | 27 | 7249.600 | 268.504 | | |
| sp | 6 | 13508.421 | 2251.404 | 16.054 | .0000 |
| g x sp | 12 | 1125.159 | 93.763 | .669 | .7797 |
| Error | 162 | 22719.359 | 140.243 | | |
| c x s | 6 | 20326.360 | 3387.727 | 16.777 | .0000 |
| g x c x s | 12 | 1483.096 | 123.591 | .612 | .8299 |
| Error | 162 | 32711.631 | 201.924 | | |

effect of condition @ sp 2: $F(1,27)=59.96$, $p<.0001$

effect of condition @ sp 7: $F(1,27)=30.87$, $p<.0001$